APPENDIX B
EXAMPLES OF COLD-MIX AND HOT-MIX RECYCLING PROGRAMS

B-1. Cold-mix recycling problem.

The middle 50 feet of an airfield taxiway is to be removed to a full depth (3 to 5 inches), replaced with a recycled cold mix, and overlaid with 3 inches of new hot mix. The design mix must be developed for the recycled cold mix.

a. Step 1. Obtain samples of the in-place pavement (use jackhammer or other acceptable means).

b. Step 2. Run an extraction on the old asphaltic pavement to determine the following:

(1) *Asphalt content.* Use the determination of the existing asphalt content as a guide to calculate how much, if any, additional asphalt binder will be needed.

(2) *Asphalt penetration.* Perform a penetration test to determine if the existing asphalt has become so brittle that it needs rejuvenating. If possible, avoid using a rejuvenator with recycled cold mixes. Until the rejuvenator penetrates the old asphalt, the mix is unstable and could remain unstable for as long as 2 months. Generally, a slow-set asphalt emulsion is preferred for cold-mix recycling.

c. Step 3. Prepare a set of samples varying the amounts of asphalt emulsion added, and compact at 75-blow compaction effort at a temperature of 250 degrees F. Vary the amount of asphalt emulsion added from 0 to 2.5 percent in 0.5 percent increments. This range will generally be large enough to bracket the optimum amount of emulsion to be added.

d. Step 4. Test the samples obtained in step 3 for stability, flow, unit weight, percent voids total mix, and percent voids filled with asphalt. Record the test results in plots similar to those shown in figure B-1. The plots in figure B-1 are used to determine the optimum asphalt emulsion to be added.

e. Step 5. Using figure B-1 and the procedure outlined in TM 5-822-8/AFM 88-6, chap 9, and TM 5-825-2/AFM 88-6, chap 2, select the preliminary optimum asphalt emulsion to be added as follows:

Determination of Optimum Bitumen Content

Selection Point	Asphalt Emulsion Added
Peak of stability curve	0.5 percent
Peak of unit-weight curve	1.0 percent
4 percent voids in total mix	1.0 percent
75 percent total voids filled with asphalt	0.0 percent
Average	0.6 percent

f. Step 6. Determine the optimum water content by preparing a set of samples of various water contents (0.6 percent added asphalt emulsion held constant) using the 75-blow compaction effort at the approximate temperature at which the reclaimed asphalt concrete will be during construction.

g. Step 7. Using the data obtained in step 6, plot the dry density versus the water content, as shown in figure B-2. Pick the peak of the curve to obtain the optimum water content. For the example, the optimum water content is 2 percent.

h. Step 8. Adjust mix during laydown operations as needed.

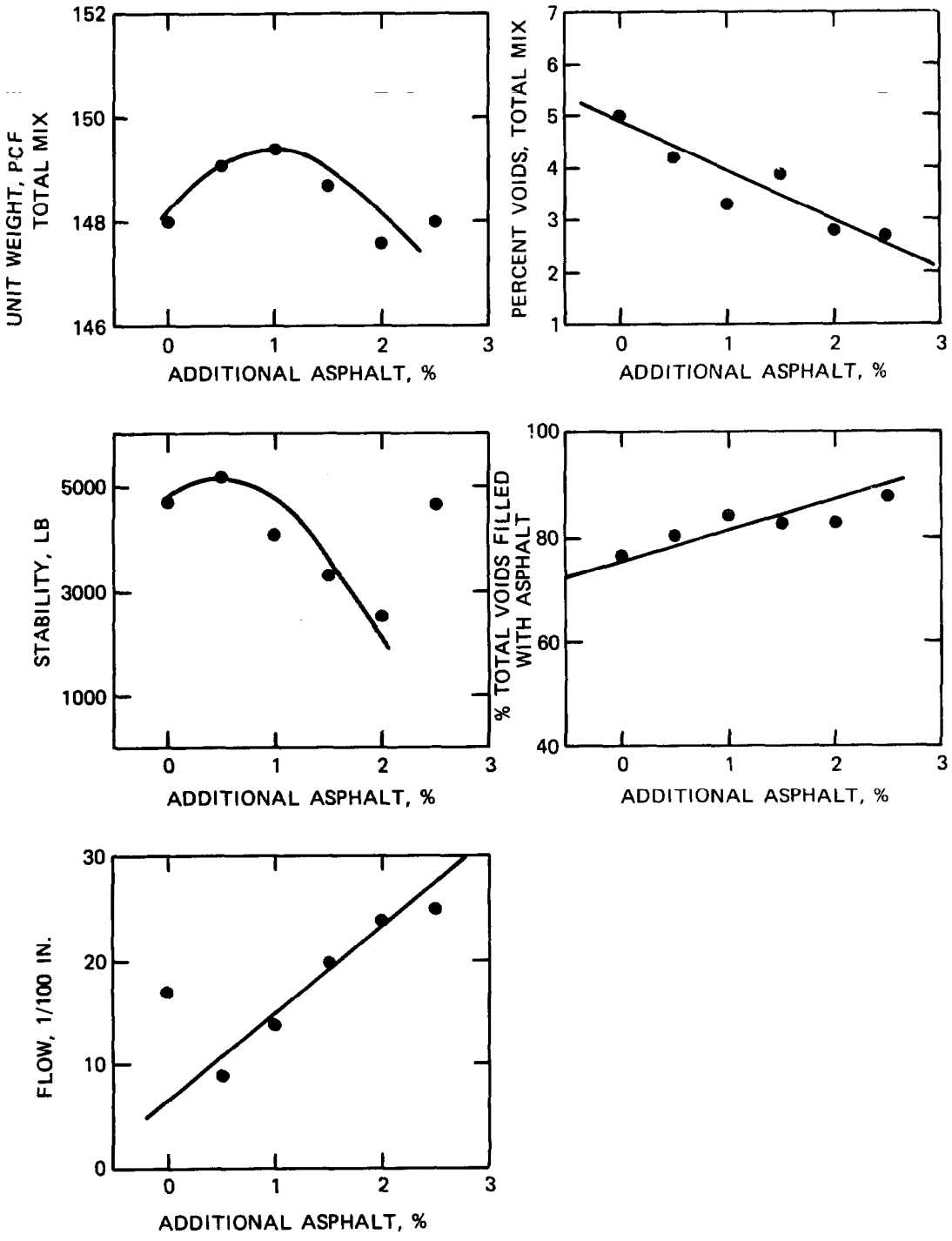

Figure B-1. Recycled cold-mix design using asphalt emulsion.

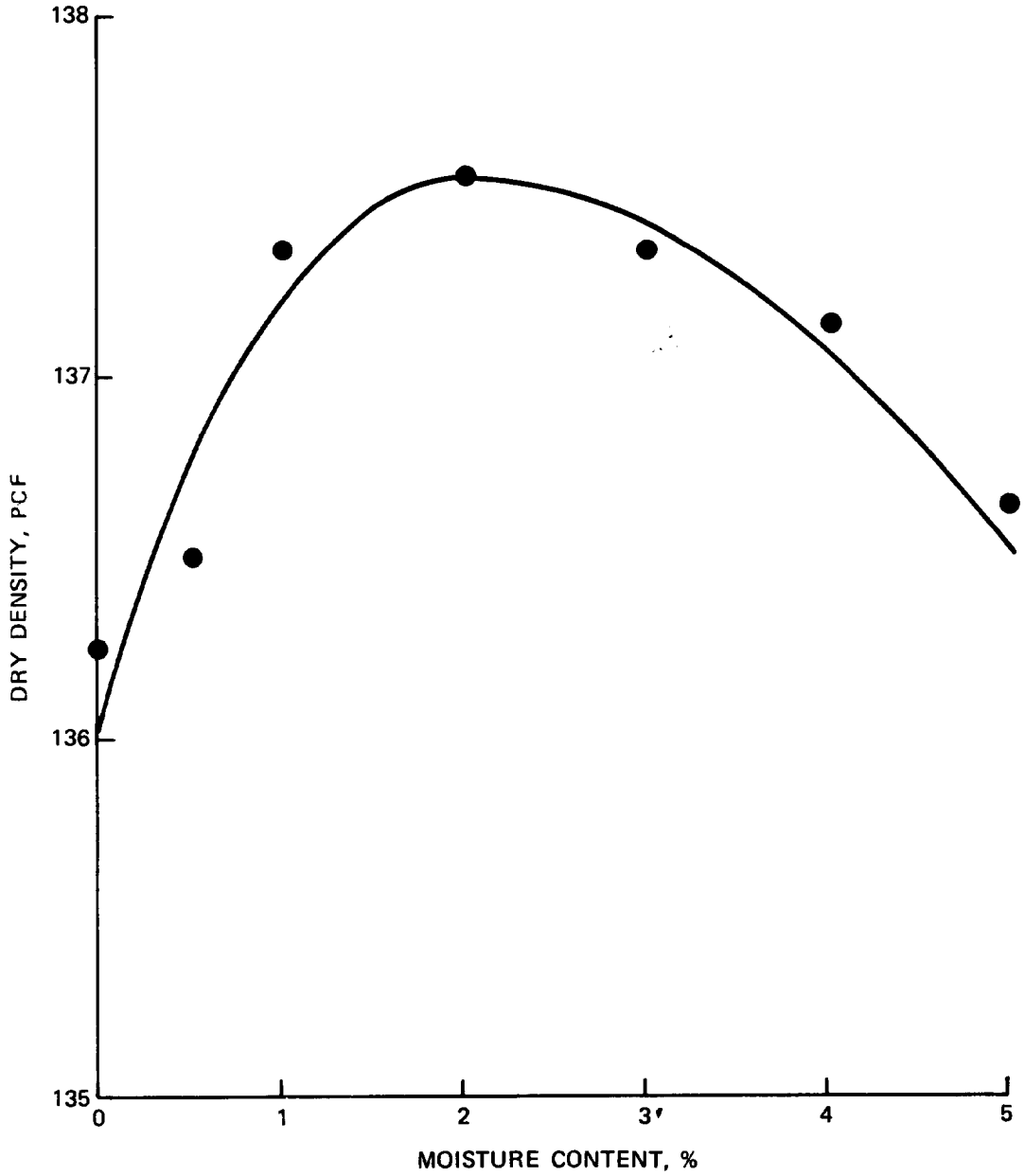

Figure B-2. Determination of optimum moisture for cold-mix design.

B-2. Hot-mix recycling problem.

The middle 75 feet of a runway is to be removed full depth (3 inches) and replaced with a recycled asphalt mixture containing 50 percent reclaimed asphalt pavement. Develop the design mix.

a. Step 1. Obtain samples of the in-place pavement (use jackhammer or other acceptable means) along with samples of the new aggregates to be used and the new asphalt and recycling agent, if needed.

b. Step 2. Run sieve analyses on all aggregates including aggregate extracted from sample of the in-place asphalt mixture. If an adequate history upon which to evaluate the new aggregate is not available, use the standard tests as outlined in TM 5-822-8/AFM 88-6, chap 9, and TM 5-825-2/AFM 88-6, chap 2. The history of the performance of the old aggregate should suffice for its evaluation. The aggregate gradations are shown in table B-1.

Table B-1. Aggregate gradations

Sieve Size	Percent Passing			
	Reclaimed Asphalt Pavement	New Coarse Aggregate	New Fine Aggregate	New Natural Sand
3/4 in	100	100	100	100
1/2 in	95	95	100	100
3/8 in	83	75	100	100
No. 4	63	12	100	98
No. 8	52	2	79	95
No. 16	40	0	57	89
No. 30	29	0	42	77
No. 50	21	0	30	48
No. 100	12	0	18	12
No. 200	6.0	0	8.0	4.5

c. Step 3. Determine the percentage of each aggregate to be used so that the gradation requirements for the blend are satisfied. The gradation requirements for this job are outlined in table B-2. The gradation requirements for recycled hot mix are the same as those for new mixtures. Through trial and error it was determined that a blend using 50 percent reclaimed asphalt materials, 24 percent coarse aggregate, 19 percent fine aggregate, and 7 percent natural sand would satisfy the gradation requirements (table B-2).

Table B-2. Gradation of recycled mixture

Sieve Size	Percent Passing	
	Specifications	Recycled Mixture
3/4 in	100	100
1/2 in	82-96	95
3/8 in	75-89	86
No. 4	59-73	60
No. 8	46-60	48
No. 16	34-48	37
No. 30	24-38	28
No. 50	15-27	20
No. 100	8-18	10
No. 200	3-6	4.8

d. Step 4. Conduct a penetration test on the recovered asphalt. A penetration test on the asphalt recovered from the in-place asphalt mixture indicated that the asphalt penetration was 10 percent. The target penetration for this example (mild climate) is 50. Because of the low penetration, it will be necessary to use a low-viscosity asphalt cement AC-2.5) and possibly an asphalt recycling agent.

e. Step 5. Prepare a set of samples with various asphalt contents with no recycling agent and a set of samples at various asphalt contents with 0.5 percent recycling agent. The added asphalt content should be varied from 2.5 to 4.0 percent for the samples with no recycling agent and from 1.5 to 3.0 percent for the samples with 0.5 percent recycling agent. Figure B-3 shows the properties of the mixtures with various added asphalt contents and 0.5 percent recycling agent. Figure B-4 shows the properties of the mixtures at various asphalt contents with no recycling agent.

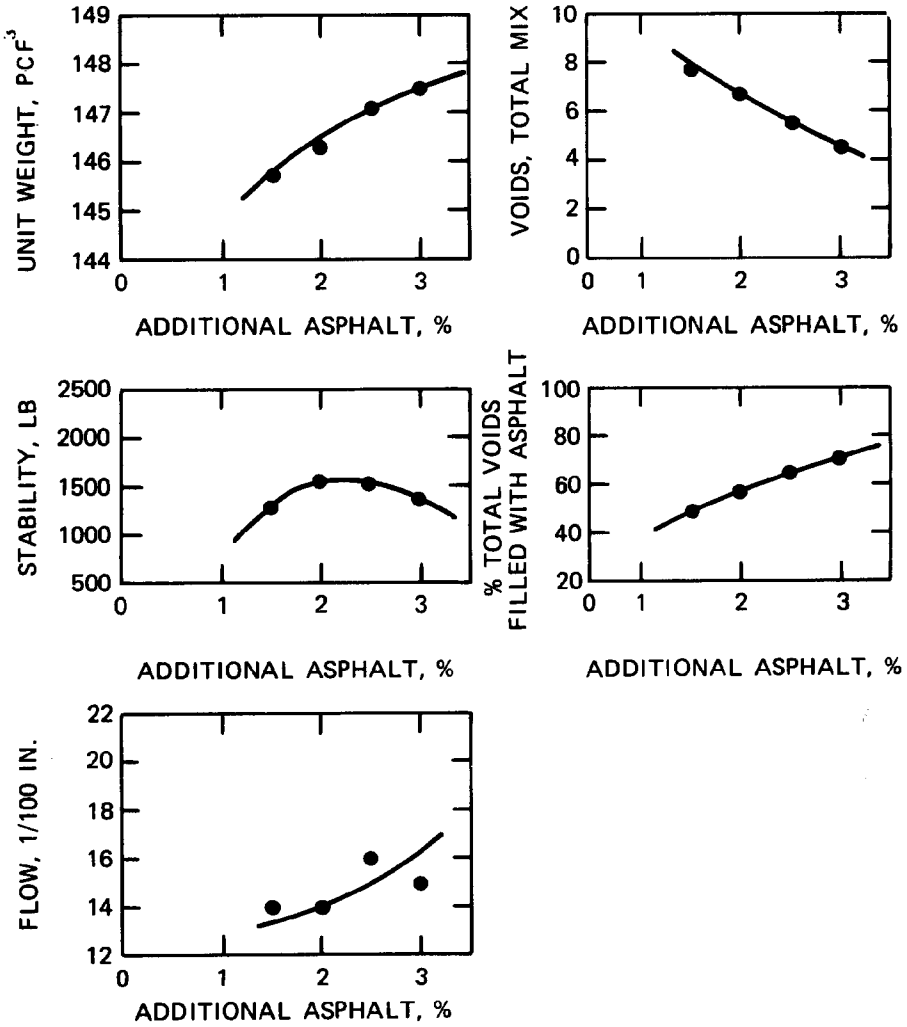

Figure B-3. Recycled asphalt concrete mix design for recycled hot mix; AC-2.5 asphalt binder and 0.5 percent recycling agent.

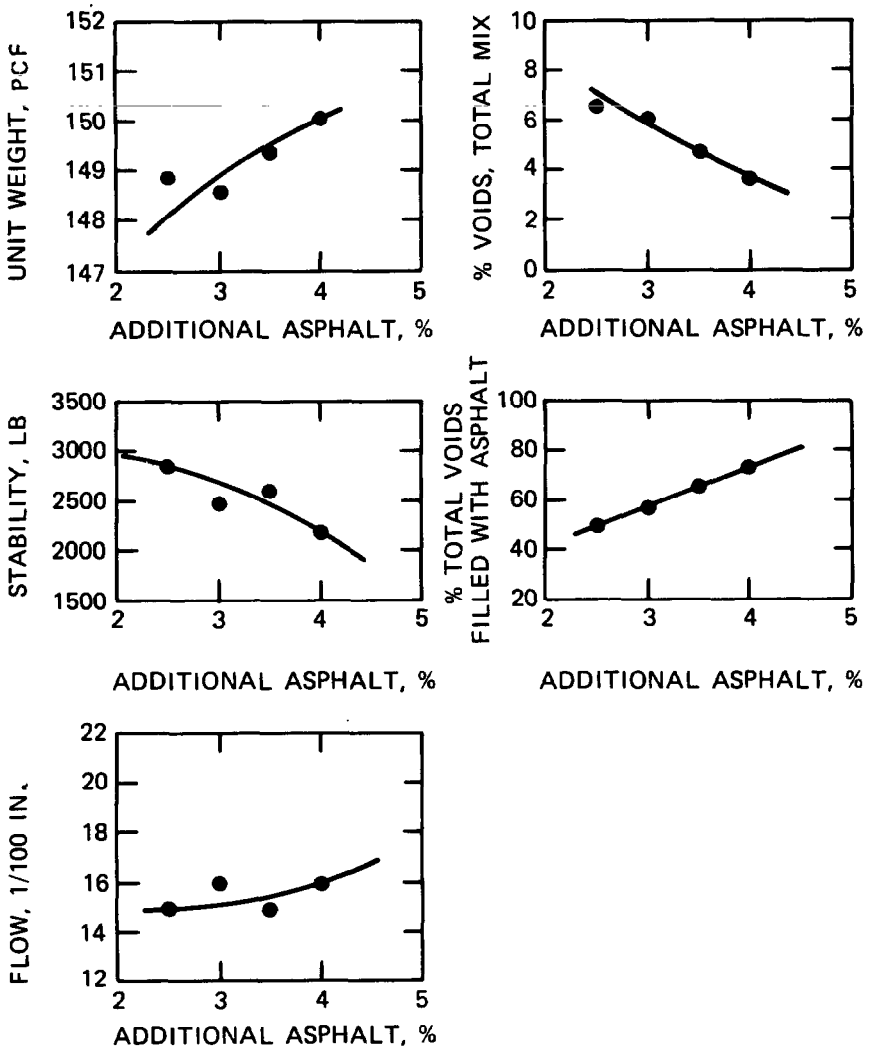

Figure B-4. Recycled asphalt concrete mix design for recycled hot mix; AC-2.5 asphalt binder with no recycling agent.

f. Step 6. Select the optimum asphalt content for the mixture with no recycling agent and for the mixture with 0.5 percent recycling agent. The optimum asphalt content and mixture properties for the two mixtures, as well as the penetration of the asphalt cement recovered from these two mixtures, are listed in table B-3.

Table B-3. Asphalt mixture properties at optimum asphalt content

Property	Mixture With No Recycle Agent	Mixture With 0.5% Recycle Agent
Optimum asphalt content, percent	4.0	3.0
Density, pcf	150.1	147.5
Stability, lb	2200	1450
Flow, 0.01 in.	16	16
Voids total mix, percent	3.9	4.5
Voids filled with asphalt, percent	75	72
Penetration of recovered asphalt binder, 0.1 mm	40	90

g. Step 7. Select a preliminary mix design to provide penetration of recovered asphalt binder to be approximately 50 by interpolating between penetration values of 40 and 90 as determined in step 6. The change in penetration with a change in recycling agent is not linear, but for the preliminary mixture design a linear interpretation is sufficient. The properties at optimum asphalt and recycling agent contents are presented in table B-4.

h. Step 8. At start-up of plant operations, modify the mix design to suit field conditions. The properties of the asphalt binder can be adjusted without changing other mix properties significantly by increasing the amount of recycling agent slightly and decreasing the amount of asphalt cement by the same amount or vice versa. Failure to modify mix design to meet field conditions may result in an unsatisfactory mix.

Table B-4. Mixture properties at optimum asphalt and optimum recycling agent content

Property	
Optimum recycling agent content, percent	0.1
Optimum added asphalt content, percent	3.8
Density, pcf	149.6
Stability, lb	2050
Flow, 0.01 in.	16
Voids total mix, percent	4.0
Voids filled with asphalt, percent	74
Penetration of recovered asphalt binder, 0.1 mm	50